Performance Testing of Durable, Cleanable Aircraft Coatings

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Abstract: The Air Force Research Laboratory (AFRL) and its contractors, SAIC and Battelle are currently assessing the durability and cleanability of new aircraft coatings submitted by coatings vendors. Over 75% of the hazardous wastes generated by the Air Force are directly related to the painting/depainting process, and a large part of this topcoat repainting occurs at the field level. Low gloss polyurethane topcoats are difficult to clean due to surface roughness, and the polyurethane based topcoat fades and chalks due to ultraviolet (UV) exposure from the sun. These two effects and their combination discolors the topcoat, resulting in the need for repainting. The Air Force prepared a detailed list of performance requirements based upon user input emphasizing cleanability and weatherability. The laboratory tests developed by SAIC and Battelle will measure conformance with these requirements. Publicized breakthroughs in industrial coatings technologies showed promise if they could be modified for low gloss military applications. AFRL solicited coatings manufacturers, researchers, and formulators for innovative coatings that meet the prescribed requirements. These vendors submitted wet samples and coated aluminum panels for testing. The submitted samples are undergoing extensive testing to determine general performance properties such as water and solvent resistance, flexibility, adhesion, surface hardness, abrasion resistance, environmental exposure, and cure characteristics. In addition, the test regimen will examine the effects on the performance properties of multiple stresses from temperature extremes, cyclic loads, rapid decompression, and UV exposures. The first round of initial screening tests is complete and several candidates show promise of improved hardness and cure time. Following the complete array of laboratory tests, SAIC and Battelle will determine which coatings show promise as potential replacements for existing formulations and make recommendations to AFRL on fielding these replacements.

INTRODUCTION

The most difficult environmental problems associated with aircraft maintenance operations come from the use of coatings to protect the aircraft from weathering and corrosion. These coatings and the solvents used to apply them contain hazardous materials that are harmful to painters and the environment. Three quarters of all Air Force hazardous waste is due to the application and removal of aircraft coatings. Of the 438,000 lbs. of volatile organic compound (VOC) generated each year at the Air Force's depots, approximately 220,000 lbs. are due to the paint application process. The Air Force also estimates that field-level aircraft painting generates 700,000 lbs. of VOCs annually[1]. Department of Defense aircraft maintenance operations have had limited success in identifying alternative low-VOC and aqueous coatings that do not require the use of EPA 17 chemicals for formulation or application. Military aircraft have a low gloss (<5 gloss units) requirement that requires high pigment loading in the paint. The high pigment loading results in a physically rough surface that diffuses light, resulting in low gloss. This rough surface holds dirt and other contaminants (oils, hydraulic fluids), making cleaning difficult. In addition, the relatively low resin content is extremely sensitive to ultraviolet degradation from the sun. This results in chalking and discoloration, and when combined with poor cleanability is forcing the field units to touch up and repaint at an environmentally unacceptable frequency. Environmentally compliant coatings are offered commercially, but the coatings that the Air Force has evaluated do not meet the performance requirements for military aircraft. As a result, DoD installations must spend more time reapplying and repairing aircraft coatings, which can increase waste generation rates and affect operational readiness. Thus, the Air Force seeks to identify environmentally preferable aircraft coatings that are significantly more durable and cleanable than currently used aircraft topcoats.

PERFORMANCE REQUIREMENTS AND PROJECT DESIGN

Before conducting performance testing on aircraft coatings, AFRL first had to define the requirements for an effective coating. Engineers at the AFRL Materials and Manufacturing Directorate solicited inputs from the F-15 System Program Office, the Warner Robins Air Logistics Center, and Air Combat Command in preparing these requirements. Common inputs received were improved hardness of the coating to resist scuffs and scrapes during ground maintenance and reduced cure time for improved turnaround. An effective aircraft coating must meet the environmental requirements of the National Emission Standards for Hazardous Air Pollutants (NESHAPs) rule[2] for aerospace manufacturing and rework facilities, which stipulated that all uncontrolled topcoats must not exceed 420 g/l in volatile organic compounds or organic HAPs. In addition, the Air Force has committed to the reduction of the usage of the EPA 17 Industrial Toxic Chemicals[3,4], several of which are often used in aircraft coating formulations[5]. These regulations formed the basis for the environmental component of the requirements for a durable, cleanable aircraft coating. Therefore, an acceptable coating must comply with the NESHAPs rule and contain no EPA 17 chemicals in its applied form.

The limitations on the constituents and concentrations of chemicals in the coatings were combined with a list of extremely rigorous performance requirements, which AFRL selected to define the durability and cleanability of the coating. These performance requirements are presented in Figure 1 below.

General Properties	*Wet Properties*	*Film Properties*
weathering resistance cleanability with aircraft cleaners fluid resistance mar resistance humidity resistance heat resistance abrasion resistance	pot life drying time viscosity shelf-life freeze-thaw stability	flexibility adhesion rain erosion resistance color gloss infrared reflectance

Figure 1. Performance Requirements for Aircraft Coatings

AFRL assembled all these requirements into a *Durable, Cleanable Coatings Requirements Document*[6], which was distributed to coatings manufacturers and formulators in July of 1997 to encourage these vendors to prepare a coating sample that could meet these requirements. To assist in guiding materials development, the requirements document was broken into two sections: general requirements and desired properties. Conformance to the general requirements were of greatest importance: specimen preparation, environmental compliance, compatibility with existing painting equipment and situations, and environmental resistance. Environmental resistance required that candidate topcoat candidates meet artificial weathering (Xenon and Carbon Arc, UV Condensate) and cleanability exposures with minimal color change ($\Delta E < 0.3$). AFRL provided the desired properties to allow vendors to “trade off” other coating properties for the more important durability and cleanability requirements.

After AFRL distributed the *Coatings Requirements Document* to interested vendors, they conducted a meeting at Wright-Patterson AFB to answer any questions and to explain the purpose and schedule for the durable, cleanable coating project. AFRL informed the vendors that it was seeking samples of coatings that could meet or exceed the properties described in the *Coatings Requirements Document* and that it would conduct testing on these samples to determine if the coatings met the requirements. AFRL contracted with SAIC and Battelle to conduct performance tests on the coatings submitted by vendors.

The schedule for the evaluation of coatings submitted by vendors is shown in Figure 2 below. After AFRL held the meeting with coatings vendors, Battelle developed the test plans and prepared the sample submittal procedures. Battelle sent these procedures to the vendors along with an invitation to submit coatings samples for evaluation. Battelle received the coating samples and conducted the initial screening tests using the tests outlined in the initial screening test plan. Battelle will conduct full laboratory tests of these samples and prepare an interim test report based on the first round of testing. Battelle will repeat the testing process, after informing the coatings vendors of the results of the first round of testing. This will allow vendors to modify their formulations against deficiencies identified during testing and attempt to improve their performance. After completing a second round of testing, Battelle will prepare a final test report that will summarize the results of the overall effort.

Activity	*Date*
Project Start	July 1997
Test Plan Development	October 1997 to January 1998
Coating Sample Submission I	January 1998
Initial Screening Tests I	February 1998 to April 1998
Full Laboratory Tests I	May 1998 to August 1998
Interim Test Report	October 1998
Coating Sample Submission II	October 1998
Initial Screening Tests II	October 1998 to December 1998
Full Laboratory Tests II	December 1998 to March 1999
Final Test Report	April 1999

Figure 2. Schedule for the Evaluation of Vendor-Submitted Coatings

SAMPLE SUBMITTAL

AFRL invited coatings vendors to prepare samples that would meet or exceed the specifications described in the *Coatings Requirements Document*. The procedure for sample submittal called for a wet sample of the coating and a set of coated aluminum panels, with the coating applied over a chromate conversion coating (MIL-C-5541) and standard Air Force primer (MIL-P-23377G, Type I, Class C). The coated panels were used only for the initial screening tests [see Initial Screening Tests below]. Battelle used the wet samples to prepare coated panels for the full laboratory tests. Battelle also prepared the panels with a chromate conversion coating and standard primer, which is typical for Air Force aircraft.

INITIAL SCREENING TESTS

In the screening tests, Battelle evaluated coated aluminum panels supplied by the vendors and the cure characteristics of wet samples as applied to aluminum panels in the laboratory. Battelle designed the initial screening tests to identify processability, durability and cleanability deficiencies. The cure profile will determine if a coating will provide the desired level of water resistance and durability after a 48-hour cure. For the initial screening tests, Battelle conducted the tests listed in Figure 3 below.

Battelle developed a cyclic temperature test and rapid decompression test to generate the types of coating failures (microcracking, blistering, and delamination) observed in operational aircraft. The repeated washing test exposed painted specimens to repeated scrubbing using a cleaning pad and cleaner used in the field. After the washings, Battelle evaluated the panels using color and gloss change as the discriminating factor.

Tests Performed
Pencil hardness test
Hoffman scratch test
solvent resistance test (MEK double rubs)
water resistance test
mar test
cyclic temperature test
rapid decompression test
GE impact test
cleanability test
repeated washing test
gloss

Figure 3. Initial Screening Tests

FULL LABORATORY TESTS

Battelle designed the full laboratory tests to subject the coatings to combined stresses, measure the physical properties of the coatings, and evaluate the coatings' performance in outdoor exposure. Battelle is conducting these tests on coated panels prepared from the wet samples submitted by vendors, to eliminate any biases in sample preparation that may have been present in the coated samples submitted by vendors.

Individual Tests Performed
Pencil hardness test
Hoffman scratch test
solvent resistance test (MEK double rubs)
room temperature GE impact test
–60 °F GE impact test
conical mandrel bend
85° gloss measurement
mar test
Taber abrasion test
fluid resistance test
humidity resistance test
heat resistance test
accelerated weather test (UV-B)
outdoor weathering
electron spin resonance (ESR) measurements

Figure 4. Full Laboratory Tests

In addition to the tests described above in Figure 4, Battelle will test these coatings for a series of combined stresses selected to simulate the adverse conditions experienced by aircraft coatings in use. These combined stresses include sequential accelerated weathering, water soak, and decompression under load tests. Following these tests, Battelle will evaluate the coatings for cracks, conical mandrel flexibility, low temperature GE impact, color and gloss changes. Battelle will compare these coated panels with the individual exposures to UV-B, soak, and decompression to determine the effect of combined stresses on the coatings. Battelle will subject coated panels to another regimen of multiple stresses that includes humidity resistance, UV-B exposure, and low temperature cyclic loading. Following this series of stresses, Battelle will evaluate the panels for color and gloss changes, mar, hardness, conical mandrel flexibility, low temperature GE impact, and any visible surface defects, such as cracking or blistering.

DESIRABILITY ANALYSIS

To compare the performance of different coatings objectively, AFRL and Battelle devised a method to evaluate the test results for different tests for each coating. This method assigns a measure of utility (desirability value) to each property and allows the assignment of relative importance for each property measured. The desirability values to be used in this program are based on the extensive information gathered during the “Now-Term” Program that Battelle conducted for the Air Force[7]. Some of the parameters have been updated to reflect the more stringent desired properties for the durable, cleanable coating sought in this project as defined in the *Coatings Requirements Document.*

For each property, Battelle prepared a graph of the objective measurement of the property, as determined by laboratory testing, versus the desirability of the property, expressed on a scale from 0 to 1. For this desirability value, d=0 corresponds to a level of the property that would make the coating useless, and d=1 corresponds to a property level which cannot be improved upon. Intermediate levels of “d” correspond to intermediate levels of coating utility. After all of these identified properties are associated with a desirability curve, it is possible to obtain an average or composite desirability called “D” which is an overall measure of coating functionality and can be thought of as a property balance parameter as follows:

$$D = \sqrt[n]{d_1 \bullet d_2 \bullet d_3 \ldots d_n}$$

D is generally the weighted geometric mean so that D will also range between 0 and 1. Note that if any single property gives a zero desirability, D will also be zero. This reflects the fact that should a single property be unacceptable, D will equal 0 and the coating will be rejected. However, for a comparative study such as this project, it is important to see degrees of differences between coatings. Therefore, instead of assigning an unacceptable property a zero value, Battelle will substitute a value of 0.01. This rates the value of the property very low, but results in an overall desirability that can be rank-ordered among the coatings tested.

RESULTS

After conducting the initial screening tests, Battelle calculated individual desirability values for each property of each coating tested. From these individual desirability values, Battelle calculated a composite desirability “D”. Figure 5 presents the results of these calculations. In the first round of initial screening tests, Battelle found that none of the coatings submitted by vendors equaled the composite desirability of the control coating after a 14-day cure. Two of the coatings did achieve performance superior to the control coating after a 2-day cure.

Battelle is currently evaluating the full laboratory performance of the submitted coatings. The results of these tests will be available in an interim report submitted to the Air Force in October, 1998. Following preparation of this interim report, Battelle will conduct another round of testing on samples submitted by coatings vendors.

2-Day Cure		*14-Day Cure*	
Coating	*D*	*Coating*	*D*
Coating 1	0.77	Control	0.54
Coating 2	0.77	Coating A	0.52

Control	0.75	Coating B	0.48
Coating 3	0.44	Coating C	0.47
Coating 4	0.41	Coating D	0.37
Coating 5	0.29	Coating E	0.27
Coating 6	0.19	Coating F	0.24
Coating 7	0.17	Coating G	0.24
Coating 8	0.09	Coating H	0.15

Figure 5. Composite Desirability of Submitted Coatings after the First Round of Initial Screening Tests[8]

CONCLUSIONS

The Air Force has developed a topcoat requirements document based upon depot, field, and command needs. SAIC and Battelle have developed a rigorous testing procedure that can be used to evaluate the performance of emerging, developmental aircraft coatings against Air Force requirements. The two round evaluation protocol developed by this team will allow paint vendors to reformulate their coatings and submit additional samples for testing after the first round of full laboratory tests are complete. Following the second round of testing, the Air Force should have more conclusive evidence of the availability of commercially available aircraft coatings that meet the desired performance requirements.

ACKNOWLEDGMENTS

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ENDNOTES

[1] *Paint Stripping Equipment Reliability/Maintainability Improvement Problem Identification Study*, Southwest Research Institute, 5 April 1995.

[2] "National Emission Standards for Hazardous Air Pollutants for Source Categories: Aerospace Manufacturing and Rework Facilities". **60** *Federal Register* 45948-80.

[3] *Air Force Pollution Prevention Strategy*, 24 July 1995.

[4] Air Force Instruction 32-7080, *Pollution Prevention Program*, 12 May 1994.

[5] Typical aircraft coatings contain toluene, xylene, methyl ethyl ketone, and methyl isobutyl ketone as the solvents and thinners used to apply the coating.

[6] *Durable, Cleanable Coatings Requirements Document*, Air Force Research Laboratory, 1997.

[7] *Reliability and Maintainability Improvement, High Performance Aerospace Coating System Program,* Air Force Research Laboratory (AFRL/MLSS), contract number F-09603-90-D-2217-RZ02, 31 January 1998.

[8] Coatings are identified using different names for each column to preserve the anonymity of samples and vendors.